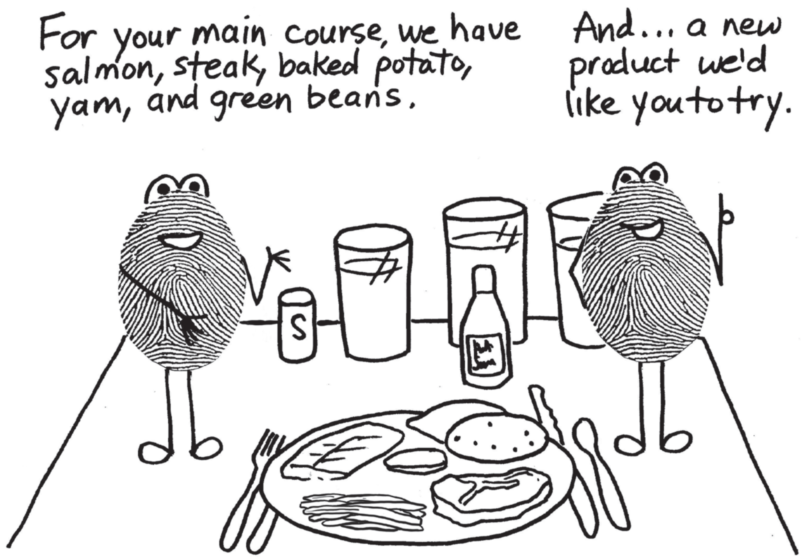
5: Main course

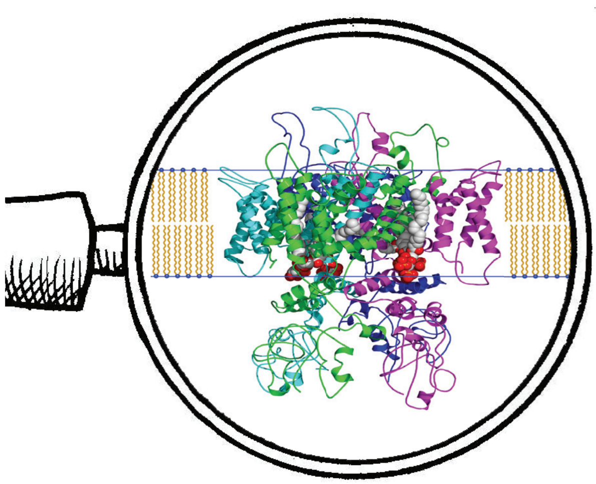


This type of main course, with both fish and red meat, is sometimes called "surf and turf." Fish live in the ocean, which has waves you can surf. Turf is a word that means a surface of grass and dirt, like a field used for grazing cows, and cows are the main source of red meat. Actually, a better name for your plate might be "Surf & Turf Plus," because we've added a third feature we'd like you to try: a newly invented plant-based meat substitute.

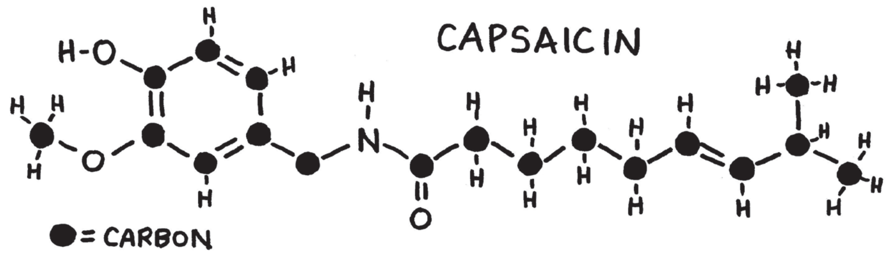
But first, let us direct your attention to that little bottle. We've provided you with some hot sauce in case you want to spice up your meat or potatoes. If you don't like having your mouth feel like it is on fire, you are welcome to say, "No, thank you." Regardless of whether you use the hot sauce or not, we'll take a look at the molecular structure of the chemical that makes hot sauce hot, and learn why it works.

First, we need to look at a microscopic structure found in the outer membrane of your nerve cells. You'll remember that we saw lots of little gadgets (made of protein) in the membranes of the green thylakoid discs inside plant cells. Some acted like pumps or shuttle buses and the biggest one was a motor that recharged ATP batteries. All cells have lots of little gizmos and gadgets embedded in their outer membranes. Some of these gadgets act as portals that control the entry or exit of certain molecules.

Here we see in our magnifier a portal with a very long name that we won't bother you with. These portals are found in your nerve cells and their job is to alert you to danger. When triggered, the portal will allow a sudden inflow of calcium atoms into the cell, which will cause the cell to generate an electrical signal that will eventually be sent to the brain. The brain will interpret this particular signal as heat. If the signal is very strong, your attention will be drawn to where the signal is coming from in case you need to do something like get your hand away from the source of the heat.

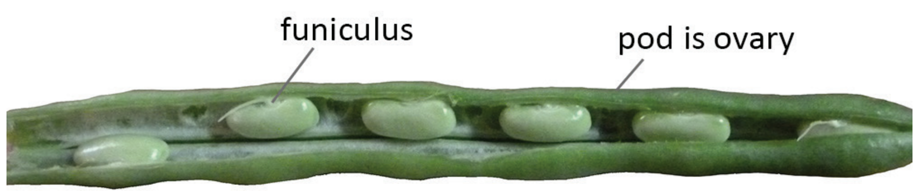


This portal can be triggered by a number of things, including: 1) temperatures above 109ºF (43ºC), 2) the presence of many protons (usually from an acidic substance), 3) a chemical that is found in mustard and in wasabi, and 4) a chemical called ***capsaicin*** *(cap-SAY-sin)* which is found in hot peppers. No matter what triggers the portal, the same signal will be sent to the brain: "HOT!"



Here is the capsaicin molecule. Something about its shape is just right to trigger that portal. There's isn't anything "hot" about the molecule. It's just a molecule. But it triggers that portal and a signal is sent to the brain, and the brain interprets the signal as a hot sensation. Most mammals have this same portal protein in their nerves, so hot sauce is sometimes recommended as a non-toxic way to deter wild animals from pesky behavior. For example, some people mix hot pepper seeds into the seeds in their bird feeders because squirrels are sensitive to capsaicin while birds are not. (Although the author of this book tried to use triple-hot pepper sauce to keep her border collie out of the trash and it didn't work.)

From the plant's point of view, the capsaicin is a defensive mechanism, to deter bugs and small animals from eating its fruit and seeds. The plant needs its seeds so it can make baby plants. And speaking of seeds, let's examine your green beans next. You can use your knife to cut one open.

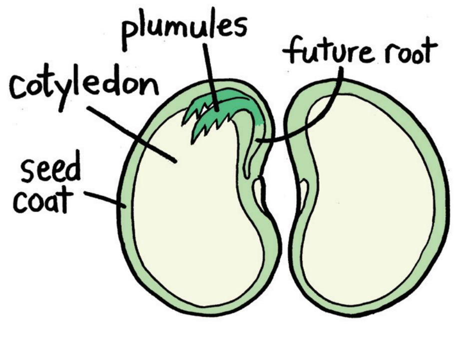


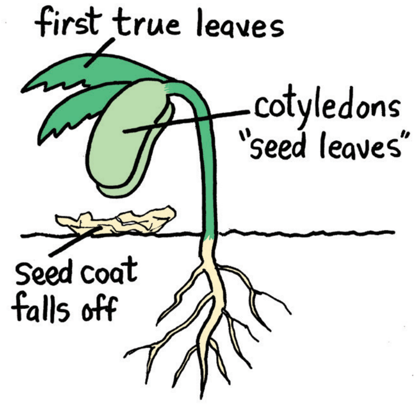
Some of your beans may have very small seeds, but a few will have seeds large enough for us to work with. We'll cut them open in a minute.

Bean pods are technically the plant's ***ovaries***. In plants, the ovary is the structure that contains the seeds. The part labeled "funiculus" is where the seed is attached to the ovary. The pod started out as a tiny ovary at the base of a bean flower. After the flower was pollinated by an insect, the seeds started to grow inside the ovary. The ovary then grew into the long green pod we recognize as a bean. We like to pick bean pods while they are still growing, well before they mature. Once they mature and start to ripen, the pods become tough and lose their sweet taste, and the beans become hard and chewy.

As you eat your beans, you can be thankful for the work of a man named Calvin Keeney who lived in New York in the late 1800s. Until Calvin started breeding bean plants, bean pods had a very prominent "string" running along the seam on one side. (This is why many people still call them "string beans.") The string wasn't very pleasant to chew and could get stuck between your teeth. It's amazing that people ate them anyway.

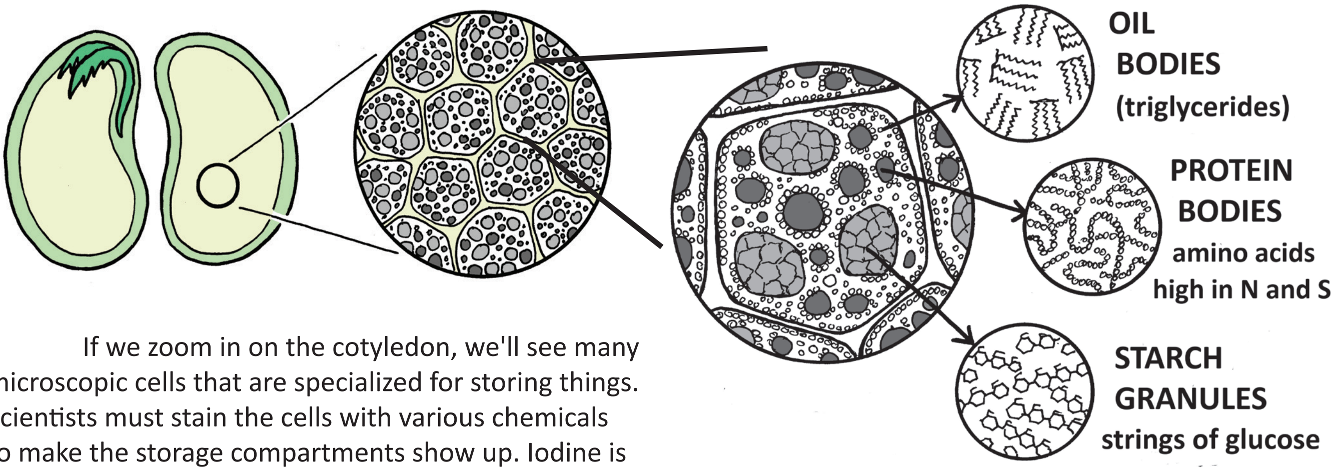
Calvin found bean plants that had slightly less stringy pods. He would breed less stringy plants with other less stringy plants and they would produce plants that were even less stringy. He kept breeding until he had produced beans with a"stringless" pod. The Burpee seed company began marketing the stringless beans in 1894 and they remained the best selling bean in the world until the Blue Lake variety was developed in the 1950s.





If we carefully slice open one of the bean seeds, we can see its anatomy. There is actually a tiny baby plant inside! This plant embryo already has two tiny leaves called ***plumules***. Below the plumules is the part that will turn into stem and roots. The bulk of the seed is called the ***cotyledon*** *(cot-ill-L EE-don)*, also known as the ***seed leaves***. Bean seeds have two cotyledons, which is why they are so easy to open; there is sort of a natural split in the middle. The seed has a covering around it, called the ***seed coat.*** The seed coat contains a lot of cellulose to make it tough, and extra phytochemicals to discourage bacteria and bugs from entering.

We are going to focus on the cotyledons, since they form most of the seed and therefore give it its nutritional properties. (The seed coats adds fiber and minerals such as zinc, calcium and magnesium.) The function of the cotyledon is to provide energy for the baby plant before it develops enough leaves to begin using photosynthesis to make its own food. The energy is mostly in the form of starch molecules.



If we zoom in on the cotyledon, we'll see many microscopic cells that are specialized for storing things. Scientists must stain the cells with various chemicals to make the storage compartments show up. Iodine is used to stain starch, for example. Our microscopic views were taken from stained samples, so we see lots of dark blobs.

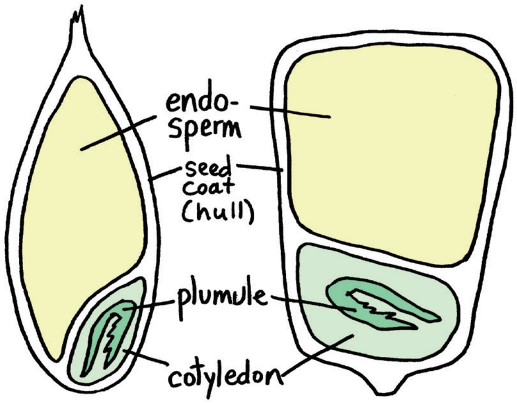
There are three types of storage vacuoles: oil bodies, protein bodies, and amyloplasts.

Oil bodies are tiny spheres made of membrane that are filled with ***triglyceride*** molecules. We've seen triglycerides several times now, so you will remember that they are made of a "hanger" molecule (glycerol) with three fatty acid "tails" made of strings of carbon atoms with hydrogens attached. We often represent these carbon chains as zigzaggy lines. The length of the carbon chains will vary, usually be between 14-22 carbons long. The oil bodies are very small and tend to cling to the outside of the protein bodies or around the edges of the cell.

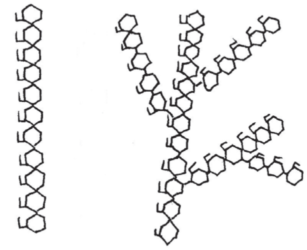
Protein bodies, which are shown as dark circles in our picture, are also surrounded by membrane and are filled with stings of ***amino acids***, especially aminos that have **sulfur** atoms or extra **nitrogen** atoms. The baby plant will need a source of nitrogen and sulfur in order to grow.

Amyloplasts store starch granules that are made of strings of glucose molecules. The length and shape of the strings differ from seed to seed. Some starch granules have a smooth appearance and other seeds make their granules with geometric shapes, looking a bit like turtle shells.

From the plant's point of view, the oil, protein, and starch are meant to feed the baby plant. Baby plants need a balanced diet with plenty of nutrients, just like you do.



Rice and corn seeds are a bit different from bean seeds. They have only one cotyledon, not two. The bulk of a rice or corn seed is called ***endosperm***. Like bean cotyledons, rice and corn endosperms store oil, protein and starch. Rice and corn tend to have more starch than beans do. The starch molecules in rice can be straight or branched, as we learned in chapter 3. In wheat seeds, the endosperm is where you find the proteins glutenin and gliadin. They would be inside protein bodies.

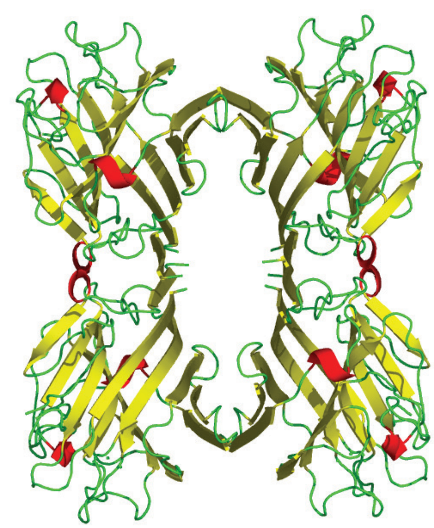


STARCH (strings of glucose)

Actually... yes. The entire bean family is toxic to some degree. Eating a few raw kidney beans can cause severe vomiting and diarrhea. Eating a handful of raw kidney beans will put you in the hospital. Green beans are much less toxic. Eating a raw green bean as you walk through your garden isn't dangerous. A large quantity of raw green beans could give you quite a stomach ache, though.

The toxic chemical in beans is called ***phytohemagglutinin*** *(fie-toe-hee-mah-glue-tin-en)* and it belongs to a large family of molecules called ***lectins***. Lectins are proteins so they are made of amino acids. Here on the right you can see how amazingly beautiful this protein is. Of course, the colors have been added, but even without the color it's still nice-looking.

If we look closely at the name of this toxin, we see "hem" in the middle, which might remind us of the word "heme" from the last chapter. Heme is the molecule in our red blood cells that carries oxygen. At the end of the word we have "agglutin" which comes from the world "agglutinate," meaning "to clump together." Wait... this sounds bad. Heme molecules clumping together? That would be nasty. And what does this have to do with bean seeds?



PHYTOHEMAGGLUTININ
Beautiful but dangerous.

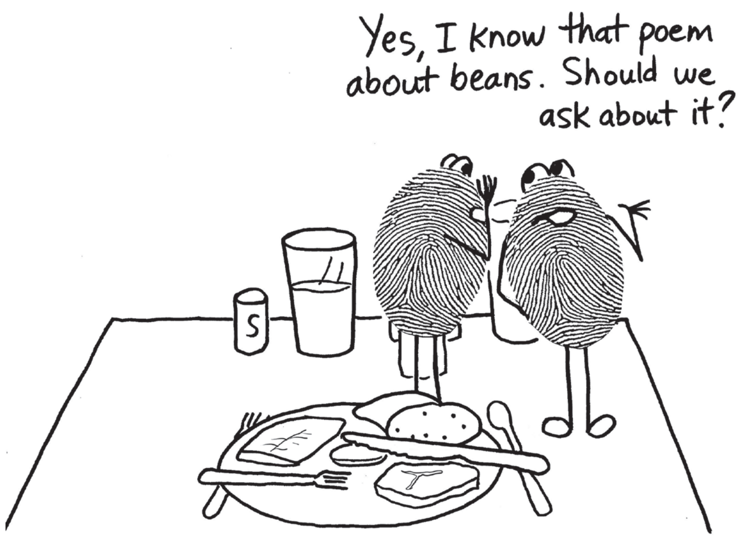
Lectins are not bad molecules. They are found throughout all kingdoms of life, and even in some viruses. They are proteins that are designed to bind to a specific type of carbohydrate molecule (made of sugars) or glycoprotein molecule (combination of sugar and protein). In human bodies, various type of lectins perform essential tasks such as promoting bone growth or regulating the amount of certain proteins in our blood. They play a role in our immune systems, helping our white cells to recognize foreign invaders.

What lectins do in plants remains somewhat of a mystery. They occur mostly in seeds, so we can guess that they play a role in germination and sprouting of seeds. Botanists guess that lectins might assist in communication between parts of a plant, or between plants, but we don't yet know how it happens.

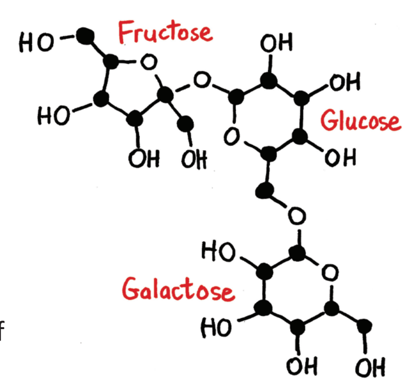
The proteins in phytohemagglutinin just happen to be the right shape to stick to little sugar strings that are on the surface of your blood cells; they act like a ball of sticky tape, holding on to multiple blood cells. (However, ingested raw beans are likely to be vomited up long before they are digested enough to get into your blood. This connection to blood is mostly a laboratory observation, not something that happens in your body.) Additionally, phytohemagglutinin can cause cells to suddenly decide to divide in half in a reproductive process called mitosis. And if that were not enough, some lectins can interfere with your ability to absorb minerals such a iron, zinc and calcium. (For this reason, lectins have been called "anti-nutrients" and have been the target of fad diets that give you a long list of things you shouldn't eat.) All these bad traits can be put to good use, however, by research scientists. Hemagglutinin molecules are a valuable tool that researchers can use to study blood and to learn about certain cellular processes.

HEMAGGLUTININ

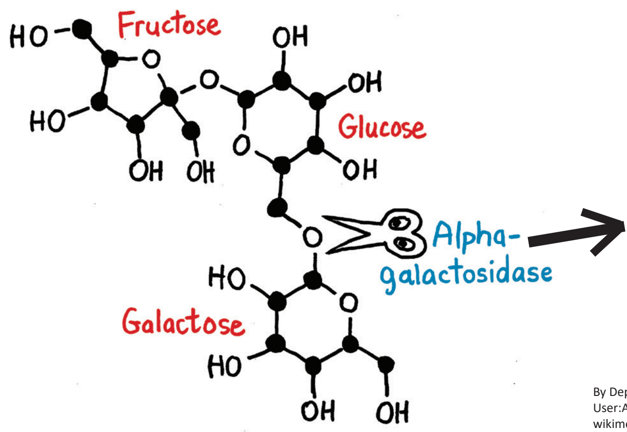
The good news (for those of us not involved in research) is that the toxicity of lectins can easily be neutralized by cooking the beans. All of the beans you buy in the store will have been washed and pre-cooked so there is no danger in eating them. Even bags of dry beans have been pre-cooked. The beans were soaked, rinsed, and then boiled at a high temperature for at least 30 minutes. There are many health benefits to eating cooked beans. They are high in fiber, protein, and minerals. Some people groups around the world eat beans almost every day, and stay healthy doing so.

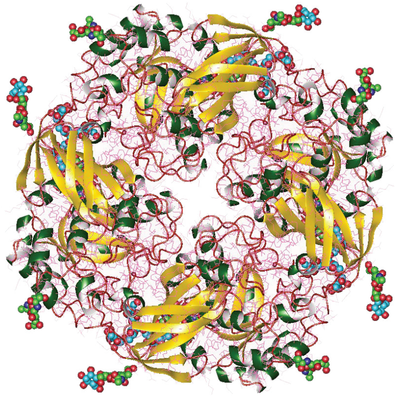


Undoubtedly you are referring to a poem whose punch line is funny because it involves intestinal gas. The scientific word for the production of intestinal gas is "flatulence," and yes, beans can do that, but the molecule that causes this problem is not a protein or a phytochemical. The offending substance is called ***raffinose***, and is found in other plants, also, not just beans. It is a small molecule made of only three simple sugars. Back in chapter one we learned about sucrose and saw that it is a disaccharide, made of glucose and fructose. Raffinose is a trisaccharide made of three simple sugars: glucose, fructose and galactose. If you stick a galactose onto a sucrose molecule, you get raffinose. You'd think that since our bodies can digest lots of sugars and starches, it wouldn't be a big deal to clip off that galactose.



However, as we've mentioned previously, enyzmes are very specific to a certain task and, as a general rule, can only do one thing. So you need the right enzyme to clip off that galactose and turn the molecule into sucrose (table sugar) that we easily digest. The name of this enzyme is ***alpha-galactosidase***. *(gal-ack-TOSE-i-dase)*





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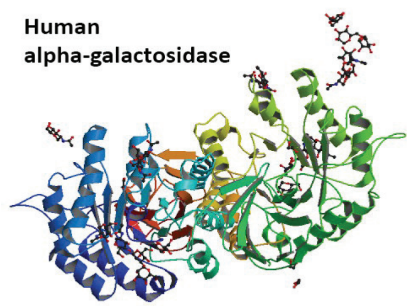
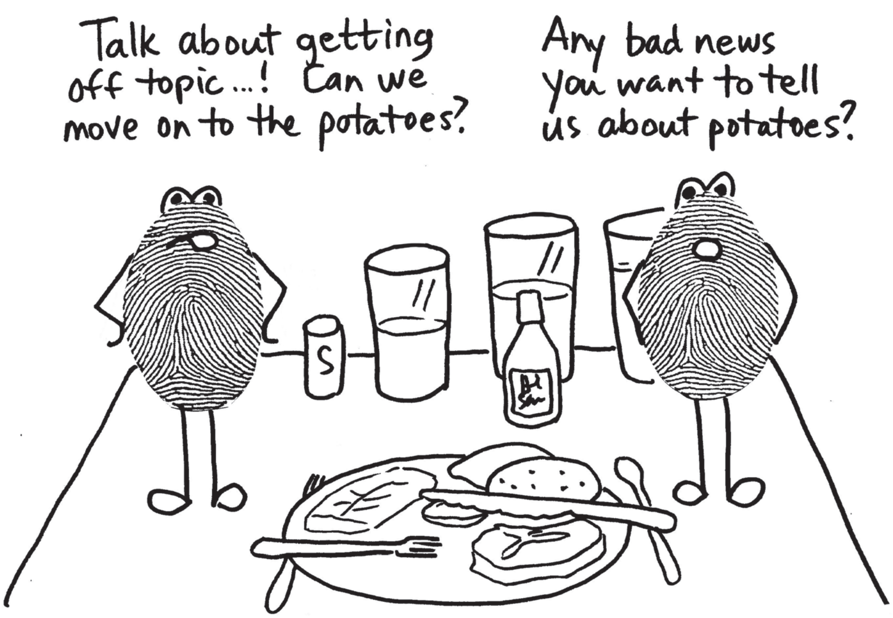
All those curls and folds are made of amino acids. The amino acids have to be in exactly the right order for this to happen. The instructions for the order in which to string the amino acids is found in DNA. Unfortunately, human DNA doesn't have the instructions for how to make this enzyme. The bacteria in your intestines, however, do have this information and therefore can make this enzyme. So when the raffinose gets to your large intestine, it's dinner time for your bacteria! As raffinose is torn apart, smaller molecules are created, including molecules of various gases. So it isn't your body creating the gas, it's your bacteria. If you would like to be able to digest the raffinase before it gets to the large intestine, you can take digestive aids, such as BeanO®, that contains alpha-galactosidase.

Humans have a version of alpha-galactosidase that can snip off a galactose sugar on the end of other short sugar strings, but not raffinose. There are lots of places on and in your cells where you'd find short sugar strings (oligosaccharides) and sometimes they need to have a galactose snipped off the end. One place you meet short sugar strings is on the outside of red blood cells. Thes oligosaccharides determine blood type (A, B, AB and O). Blood banks can use an alpha-galactosidase enzyme to turn type B blood into type O by snipping off a galactose. This is important because type O is the "universal donor" that you can give to anyone, regardless of their blood type. Ambulances carry only type O.





Yes. The bad news is that potatoes can also produce toxic chemicals. Fortunately, the potato plant produces a lot of chlorophyll alongside the toxins, so the poisonous areas are bright green and easy to see. The toxin is called ***solanine*** *(sole-uh-neen)*. Potatoes, and other plants in the "nightshade" *(Solanum)* family, such as peppers and tomatoes, produce solanine as a natural pesticide. If you are a bug, a bite of green potato could be lethal. We are a lot bigger than bugs, so it takes more than one bite to harm us. However, cases of solanine poisoning do happen, so it is always a good idea to peel off any green parts on a potato, and check to see whether the white part tastes bitter. If the white flesh is bitter, don't eat it. Symptoms of solanine poisoning include nausea, vomiting, headaches, dizziness, itching, heart palpitations, and in severe cases, paralysis. The solanine interferes with the functioning of the portals that let caclium atoms go in and out of nerve cells, so there's calcium flying around everywhere, making your nerve cells go haywire. Unlike lectins, solanine can't be destroyed through cooking, so boiling green potatoes doesn't solve the problem. You need to peel or cut off the green parts.

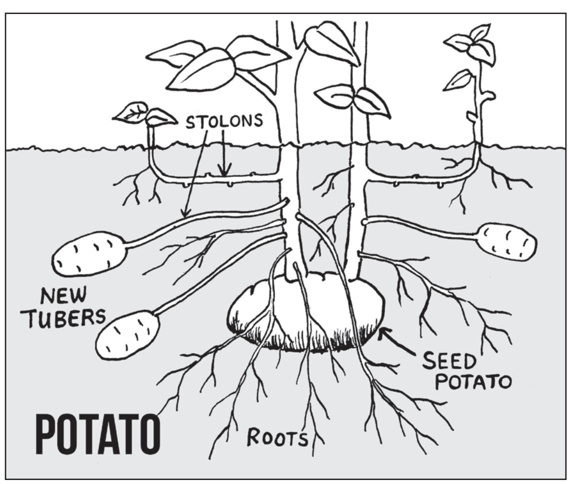
Now for the good news about potatoes. Potatoes have a lot of starch, which is a good source of calories, and they also contain many vitamins and minerals. If the skins are not green, they are a terrific source of fiber and phytonutrients. Potatoes will grow in northern climates, so they have been vital to the survival of people living at high latitudes, such as the British Isles, northern Europe, Scandinavia, and Russia.

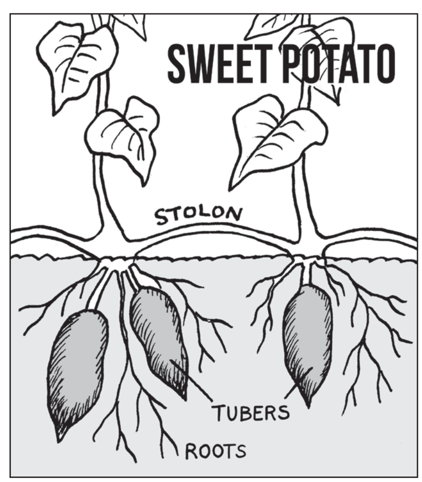
Unlike potatoes, sweet potatoes do not grow well in northern climates. They are not in the nightshade family of plants, and therefore not closely related to regular potatoes. Sweet potatoes are members of the plant family to which the "morning glory" flower belongs. Like carrots, sweet potatoes are most often orange, but can also be white, yellow, or purple.

Morning glory flowers close in the afternoon.

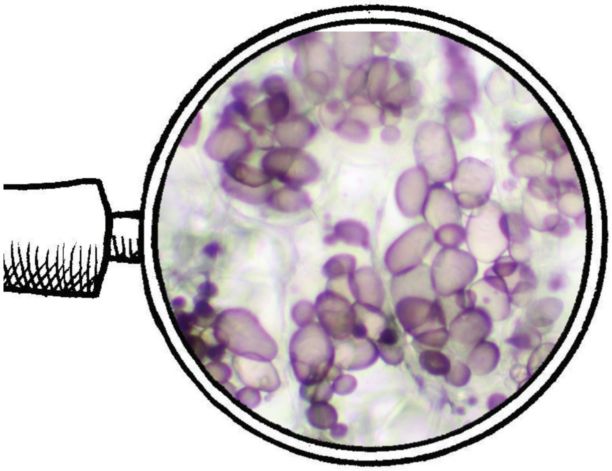
Sweet potatoes are often mistakenly called ***yams***. True yams are usually white inside, not orange, and they have a rough, brown exterior. Yams are mainly grown in Africa, whereas sweet potatoes widely distributed around the world. Scientists have used DNA evidence from archaeological sites to determine that thousands of years ago ancient travelers took sweet potatoes from Central and South America across Pacific Ocean to many island nations and finally to Japan and China. Much later, in the 1500s, Europeans who explored Central America took them back home to Europe. The word "potato" came from the name that the Taino people (on Caribbean islands) used for this food: "batata."

Since potatoes and sweet potatoes grow under the ground, it seems logical to assume that they are roots. Actually, neither of them is a root—they are both ***tubers***. Tubers are modified plant parts (often stem or root) that the plant uses to store energy. Regular potatoes are ***stem tubers*** that develop on modified stems called ***stolons***. Sweet potatoes are ***root tubers***. The cells of both kinds of tubers are filled with amyloplasts containing starches.

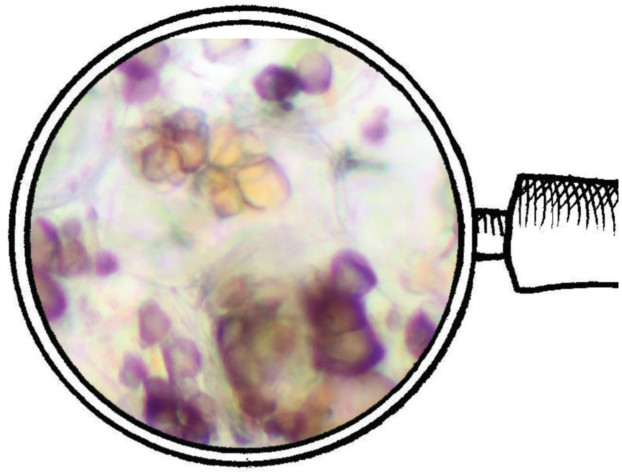




Now it is time to get out our Sooper Dooper magnifier and compare the cells of the potato and the sweet potato. Our magnifier will be used on its lowest setting, which is the same as a regular microscope in any high school or college lab. If you have a microscope at home, you can do this yourself. We will cut a very thin sliver from each kind of potato, then add a drop of iodine ("Lugol's solution") which will stain the starch molecules.

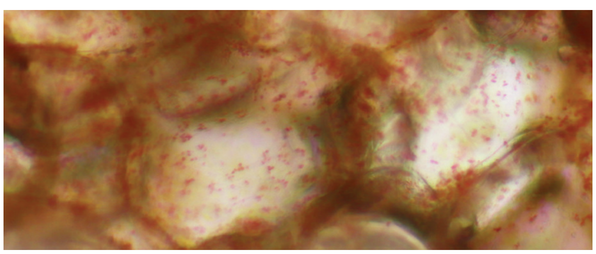


WHITE POTATO 100x

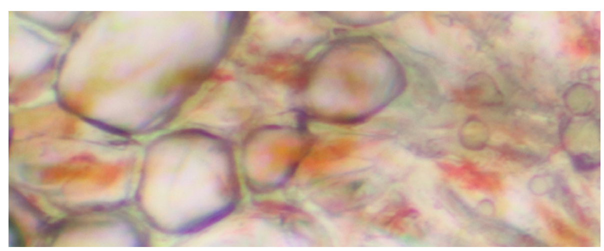


SWEET POTATO 100x

The purple ovals are the amyloplasts. The faint lines between the ovals are the cell walls. Each view shows about half a dozen cells. We can see that the sweet potato cells have orange ovals as well as purple ones. The orange ovals called ***chromoplasts***. They have not been stained; orange is their real color. "Chromo" means "color," so the chromoplasts are where you find a plant's pigment molecules.



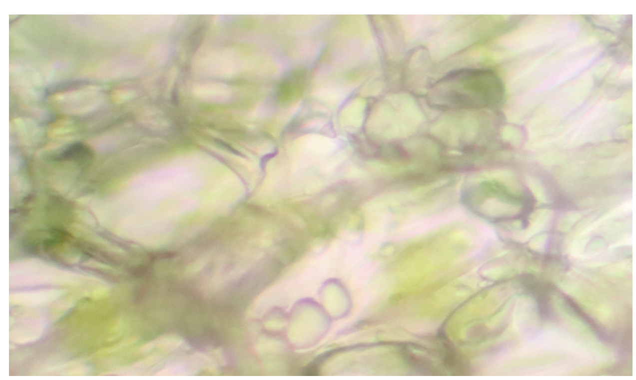
This is a thin slice of red pepper. The tiny red dots are the pepper's chromoplats.



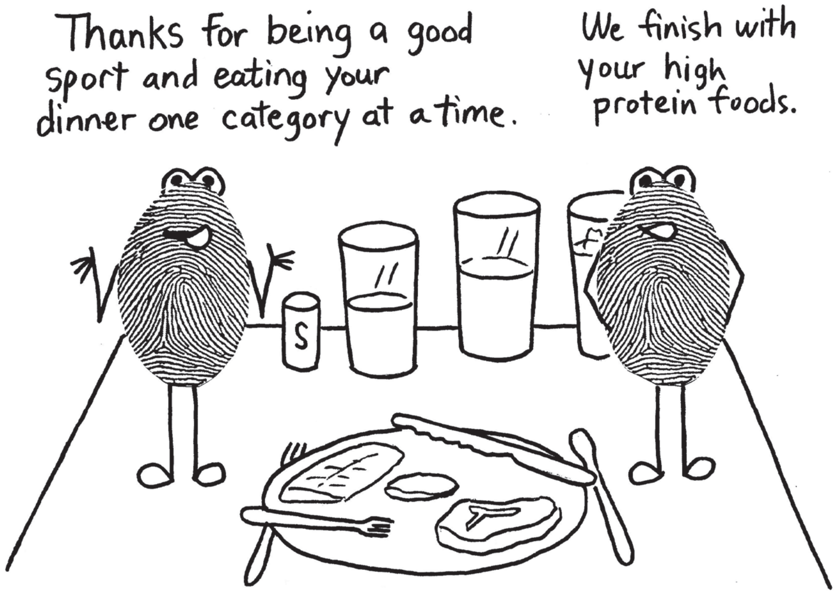
This is a thin slice of carrot. The orange chromoplasts are not as well defined and appear oblong.

Amyloplasts, chloroplasts and chromoplasts are ***plastids***. Other plastids include ***phenyloplasts***, which contain dark-colored polyphenols, and ***elaioplasts***, which store fat molecules. The cells in the skins of citrus fruits have elaioplasts, which explains the term "citrus oil." Citrus oil is used in organic insecticides.

Scientists were surprised to discover that many plastids can change their function and become a different type of plastid. We've already noted that potatoes will turn green when exposed to light. When light hits one of these potato amyloplasts, it can trigger a chain reaction that will cause the amyloplast to begin making those green thylakoid discs. The new thylakoids will begin producing chlorophyll molecules, which reflect green light. The ability of plastids to change their form is important as the plant goes through its life cycle. At some stages of its life it needs more of less of certain kinds of plastids. It is efficient for the plant to "repurpose" its plastids.



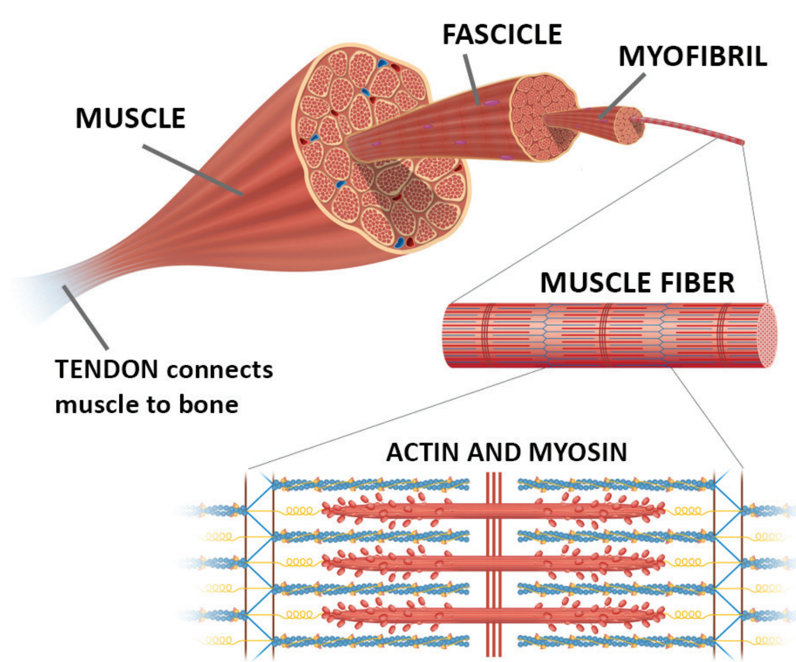
This is a thin slice of potato that is starting to go green. Some of the amyloplasts are making chlorophyll.



We've already learned what proteins are made of: amino acids. All three of the remaining foods on your plate contain long strings of amino acids that your digestive system will break apart into individual units so that your cells can use the amino acids to build their own cellular structures. Some of the amino acids you eat will be used to make the "pumps" and "motors" found in the membranes of your cells.

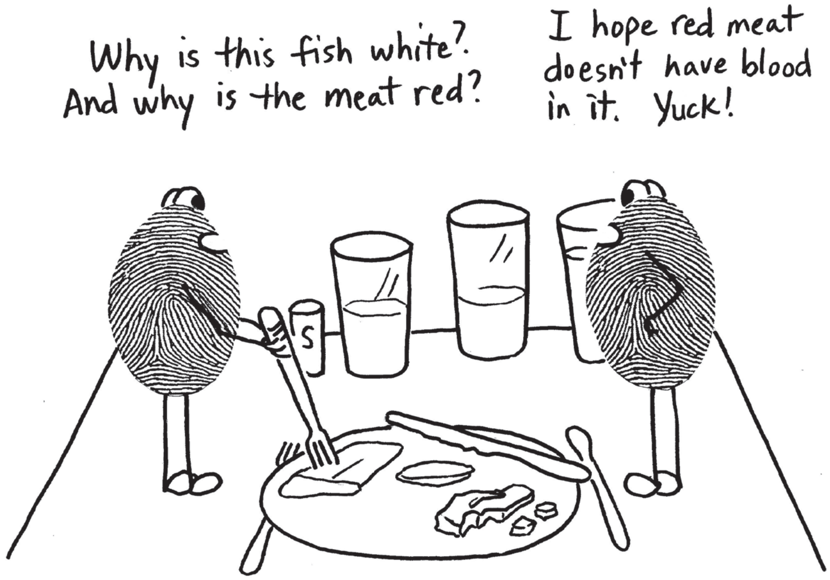
Your piece of steak is a slice of muscle and bone from a cow. You are not going to eat the bone, of course, so let's set it aside for now and let you study it in an anatomy course. The red part of the steak is made of muscle tissue. During the cooking process, the structure of the muscle tissue probably changed quite a bit, but let's pretend that it didn't change very much and find out what muscle is made of.

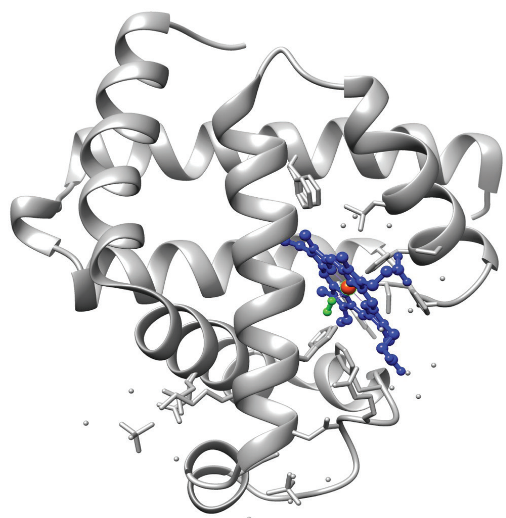
A muscle is made of bundles of bundles of bundes. The smallest bundle is called the ***myofibril*** and it is made of individual muscle fibers. Muscles don't have individual cells like other body parts do. When the muscle was forming, its cells fused together to make long fibers that have many nuclei. The fibers are packed full of two long proteins called ***actin*** and ***myosin***. (In the diagram on the bottom, actin is blue and myosin is red.) Those tiny bumps on the red myosins are like little oars that can push against the actin and cause it to slide forward. When sliding happens to thousands of fibers simultaneously, the muscle contracts, causing a body part to move. Looking at this diagram, we can see why meat often has a directional, "stringy" texture.



The digestive enzymes in our stomach and intestines will tear apart actin and myosin, breaking them into individual amino acids. Actin and myosin provide 18 of the 20 different types of amino acids.

Muscles are connected to bones by tendons. Tendons are also made of proteins (such as collagen), and they continue up the muscle, becoming more like a thin plastic bag as they cover all the bundles. If you want to observe tendons, the best place to see them is in chicken "drumsticks."





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Many people think that red meat is red because it has blood in it, but fortunately this is not true. The red color comes from a molecule called ***myoglobin***. Myoglobin is similar to ***hemoglobin***, the molecule that picks up oxygen in our lungs and carries it through the blood. At the center of hemoglobin is a molecule of ***heme***. We met heme in a previous chapter and learned that it is similar to chlorphyll. Both have a central "X" shape in the middle, made of four nitrogen atoms holding on to either a magnesium atom (chlorophyll), or an iron atom (heme). It is the iron atom in heme that causes it to reflect red light and thus make our blood appear red.

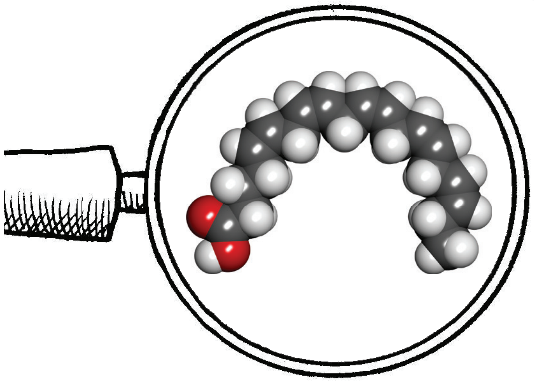
Myoglobin also has a heme at the center. In this diagram, heme is dark blue. The iron atom at the center is red, and the oxygen molecule (O_2) is green. The gray parts are proteins made of amino acids.

Myoglobin holds oxygen atoms until the muscle fibers need them. If you want to find out how long it takes for all the oxygen in your myoglobin to get used up, just hold your breath. If you stop taking in oxygen, your cells will begin to deplete all sources of stored oxygen. Animals that can hold their breath for a very long time, such as whales and seals, have a lot more myoglobin in their muscles than you do.

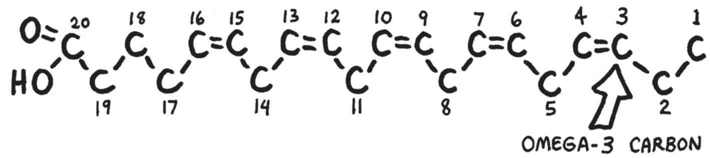
When the heme in myoglobin has an oxygen molecule stuck to it, it appears bright red. That's the red color in your meat. People like raw meat to be red, not brown, so meat packers expose the raw meat to oxygen, often in the form of carbon monoxide, CO, which sticks even tighter to heme than pure oxygen does. (This is why carbon monoxide is so dangerous!) The heme will hold on to that molecule of CO or O_2 for days, even a week or two if kept refrigerated. If meat is brown, that doesn't automatically mean that it has spoiled; it might have just lost its oxygen atoms. Smell is a better way to tell if meat is going bad.

Different animals have different amounts of myoglobin in their muscles. Fish have very little myoglobin, so their muscles don't look red. (Chickens have more myoglobin in their leg muscles, and less in their flight muscles, giving us "dark meat" and "white meat.") The orange color found in fish such as salmon comes from a carotenoid pigment called ***astaxanthin*** *(ast-ah-ZAN-thin)*. The fish get this pigment from the shrimp and krill that they eat. Flamingoes are orange for the same reason; they eat tiny orange animals.

The group of molecules that fish are most famous for are the ***omega-3 fatty acids***. If we put our magnifier on its highest setting, we can zoom in on one of these molecules and find out why they are called "omega-3." The molecule you see in the viewer is a "space filling" model that puts the atoms right next to each other instead of using a line to show the bonds. (Black is carbon, white is hydrogen and red is oxygen.) The red end is where the molecule would attach to a glyercol "hanger" creating triglyderides or phospholipids.



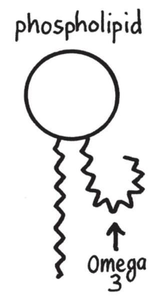
Omega is the last letter in the Greek alphabet, therefore this word is sometimes used to name things that are last in a line. Here, the line is made of carbon atoms, so the last carbon atom in the chain is the "omega carbon." The third carbon from the end is therefore the "omega-3 carbon." This is an omega-3 known as EPA: (hydrogens not shown)



The significance of the omega-3 carbon is that it is the first carbon that doesn't have two hydrogens attached to it. One hydrogen is missing, forcing that carbon atom to "double up" and form two bonds with the next carbon down the line. We show this using a double line. Every place you see a double line, there is a hydrogen atom missing. Carbon chains like this are called ***unsaturated***. Chains that have all of their hydrogens are called ***saturated***.

A carbon chain that has all its hydrogens is straight. Hydrogens don't like to be next to each other (their negative charges repel), but when the carbon chain is completely full of hydrogens (saturated), the hydrogens have no chioce but to sit there in a straight line and be unhappy. When a hydrogen leaves, this relaxes the situation and allows the hydrogens to shift their positions, and we see this as a slight curve. The molecule in our viewer has quite a few missing hydrogens, so it curves a lot.

So why are we told that omega-3 fatty acids are good for us? We don't know for sure, but one leading theory says that when these curved fatty acids are incorporated into our cell membranes as the tails of phospholipid molecules, the function of the membrane improves, especially in nerve cells. Some scientists speculate that the curved shape acts as a detangler as it moves around in the membrane. It is nearly impossible to observe a membrane "in real time" at the magnification necessary, so we might never get a definite answer. Also, some researchers say the claims about the health benefits are somewhat exaggerated. (Claimed benefits include lowering inflammation, lowering cholesterol, decreasing risk of cariovascular disease, normalizing hormone levels, and improving skin conditions.)



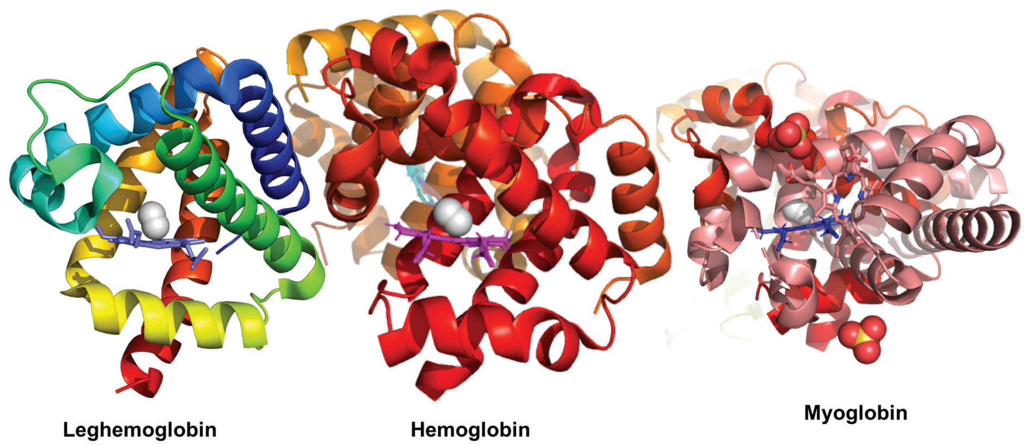
Yes, we are ready to reveal the science inside that mysterious little patty! You are right—it looks, smells and tastes like a normal hamburger. You'd never guess that it wasn't real meat. It is made of "plant-based meat," which sounds like an oxymoron (a word or phrase that is contradictory) but this term will make sense once we explain it.

There have always been meat alternatives for people who don't eat meat, but the patty on your plate is something new. It is the result of high-tech research by PhDs chemists and food scientists who wanted to find out exactly what chemicals give "red meat" (usually from cows) its characteristic smell and taste. What is it that meat-lovers love? They discovered that the key molecule is one we've already met: ***heme***. Heme is what people crave. If they could find a source of heme that came from plants instead of animals, it might be possible to make a plant-based meat that tasted like real meat.

Several decades ago, plant scientists had discovered a heme-like molecule in tiny nodules (bumps) on the roots of soybean and alfalfa plants. The roots of these plants make these tiny nodules to house a certain species of bacteria found in the soil. These bacteria can do something that plants can't do—they can take nitrogen out of the air and "fix" it into a form that plants can absorb. The bacteria are often called "nitrogen fixing" bacteria. Before nitrogen fertilizers were invented, farmers had to plant soybeans or alfalfa in their fields every three or four years. Crops like wheat or corn would take most of the nitrogen out of the soil and only soybeans or alfalfa could put nitrogen back into the soil.

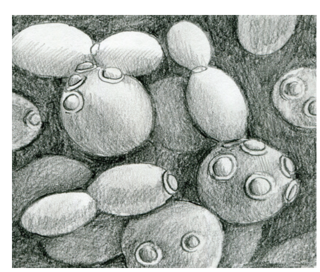
Soybean root nodules that host "nitrogen fixing" bacteria

When it became possible to analyze this heme-like plant protein, they discovered that it was most similar to myoglobin, though also very simimlar to hemoglobin. It was named ***leghemoglobin***, using "leg-" from the word "legume," which is the name of the plant family to which soybeans belong.



What a strange place to find heme! After more research, the scientists figured out why a myoglobin-like molecule was necessary inside these root nodules. The bacteria living in the nodules don't like oxygen. They need an environment with little or no oxygen. The mitochondria in the plant cells, however, need a plentiful supply of oxygen so they can make lots of energy molecules (ATPs). The leghemoglobin molecules provide a solution to this problem. They are able to grab and hold any stray oxygen molecules that come into the nodule, reducing "free" oxygen, which makes the bacteria happy. The leghemoglobins are also able to release the oxygen atoms into the plant cells, giving the mitochondria the oxygen they need for recharging ATP molecules.

The next problem was how to harvest enough leghemoglobin. Soybean root nodules take months to grow and contain only a small amount of leghemoglobin. They needed a way to scale up production so that a plant-based meat factory could produce tons of meat every day. The solution was to use genetic engineering. They were able to find the place in the soybean's DNA that contained the instructions for how to make leghemoglobin. They snipped it out and then inserted it into the DNA of a yeast cell. Now they had yeast cells that could make leghemoglobin! Yeast cells are very easy to grow in large quantities. Breweries have huge vats of them.



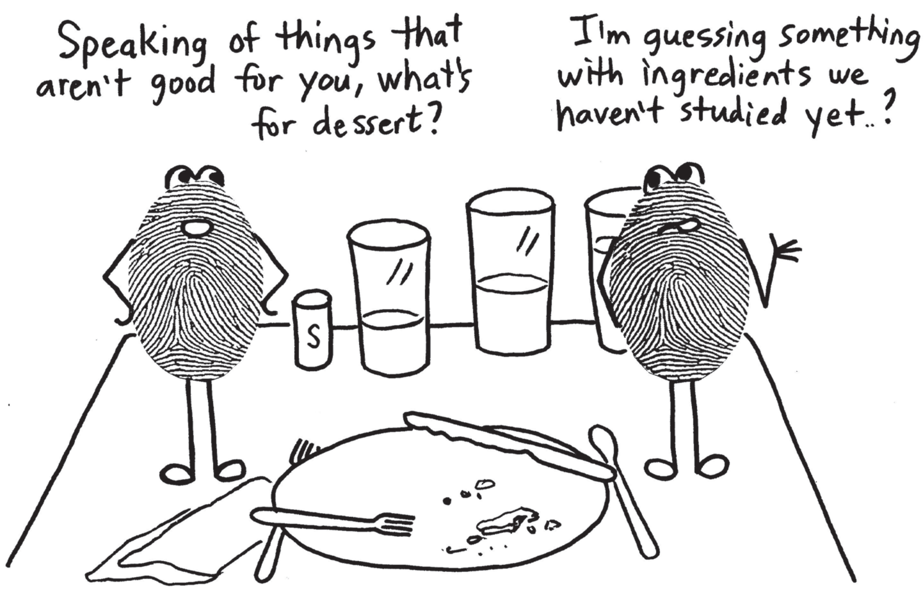
yeast cells

The meat researchers also found that there are specific amino acids and certain types of fat that combine in Maillard reactions to give that "frying beef" smell and flavor. They used super high-tech machines to analyze the aroma of cooking meat, to give them clues about what combination of plant products might give similar results. They came up with a combination of sunflower oil and coconut oil, soybeans, potato protein gel, and cellulose. Vitamins and minerals were added, also. They used professional food processing machines to chop and mash the ingredients until the texture was just right.

Some scientists are skeptical about whether this new type of plant-based meat will turn out to be safe for people to eat on a regular basis. The safety study submitted to the US FDA (Food and Drug Administration) in 2017 was a one-month study on rats. The rats were fed a much higher level of leghemoglobin than any person would ever eat, and then after a month the rats were humanely killed and all their body parts were examined.

The study found that the rats had experienced some negative changes to their body chemistry, though nothing so drastic that they look or acted sick. We'll never know what would have happened to the rats had they kept eating leghemoglobin for their entire life. It is possible that eating leghemoglobin meat carries the same risk that eating regular red meat does. Studies have shown that people who eat lots of red meat are more likely to have certain health issues as they grow older. Heme is a likely culprit for the root cause of these problems, but cooked meat (especially crispy or burnt meat) contains other types of mildly harmful molecules, too. It's hard to design a long-term food study that can isolate one ingredient.

This information isn't meant to scare anyone from eating red meat or trying the new leghemoglobin meat. With any food, we should eat in moderation.*



* Nothing in this book is intended to be medical advice about what you should or should not eat. The author is not for, or against, eating meat or meat substitutes.

Comprehension self-check

1) Capsaicin is a chemical found in this food: ___________________, that can trigger a cell membrane portal (in one of your tongue cells) that is normally triggered by: a) heat b) cold c) pain

2) Are animals sensitive to capsaicin? Are birds?

3) Bean pods are what (reproductive) part of the bean plant?

4) From the plant's point of view, what are its cotyledons for?

5) Nitrogen and sulfur are found in: a) proteins b) fats c) sugars

6) Oil bodies (in seed cells) contain what "3-legged" molecule?

7) Starch granules are made of strings of ________________ molecules.

8) Name two plants that have an endosperm and only one cotyledon in their seed:

9) What does "agglutinate" mean?

10) What does the heme molecule do in your body?

11) Phytohemagglutinin belongs to a family of molecules called l_____________, which are proteins that bind to:
a) other proteins b) sugar strings c) fatty acids d) cell membranes

12) What can you do to neutralize (get rid of) the toxic chemical found in beans?

13) A short string made of three sugars that only bacteria can digest:

14) The names of sugars end in "__ __ __" and the names of enzymes end in "__ __ __."

15) Will cooking a green potato get rid of the solanine toxins?

16) Which grows better in cold climates, potatoes or sweet potatoes?

17) TRUE or FALSE? An amyloplast can turn into a chloroplast.

18) Which are stem tubers, potatoes or a sweet potatoes?

19) Where would you be more likely to meet a chromoplast, in a potato or a sweet potato?

20) TRUE or FALSE? Meat is red because it contains blood.

21) What two proteins slide against each other in a muscle fiber?

22) What molecule holds oxygen atoms in a muscle fiber?

23) The smallest "bundle" in a muscle is called a:

24) To make raw meat keep its red color, it is sometimes exposed to ____________ _____________ during packing.

25) Where did the salmon get its orange pigment molecules?

26) What are omega-3 fatty acids missing? a) oxygen atoms b) carbon atoms c) hydrogen atoms

27) The roots of soybean plants have tiny nodules that contain _________________ that can take ___________ out of the air and make it available to plants.

28) What organism makes the heme used in plant-based meat?

29) What reaction creates delicious flavor molecules? the M_____________ reaction

30) Beans belong to the ______________ family of plants.

ACTIVITY 5.1 Matching

Each word in the numbered list has some kind of association with a word in the letter list. The associations are of different types, but you should be able to figure out which words go together. Write the correct letter in each blank. (Use the process of elimination if necessary, and start with the ones that you are sure of.)

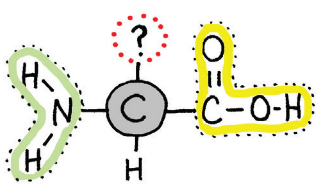
1) ___ beans
2) ___ potatoes
3) ___ amyloplasts
4) ___ peppers
5) ___ seed leaf
6) ___ true leaf
7) ___ corn
8) ___ raffinose
9) ___ sweet potato
10) ___ chloroplast
11) ___ myosin
12) ___ heme
13) ___ salmon
14) ___ triglceride
15) ___ amine

a) actin
b) astaxanthin
c) cotyledon
d) capsaicin
e) endosperm
f) fatty acids
g) green
h) nitrogen
i) plumule
j) phytohemagglutinin
k) solanine
l) alpha-galactosidase
m) starch granules
n) root tuber
o) oxygen

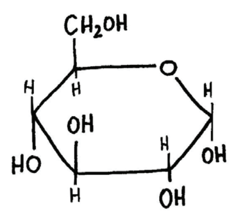
ACTIVITY 5.2 What are these things?

Match a word to each picture. All the answers are given at the bottom...plus a few extra words you won't use.

1) _______________

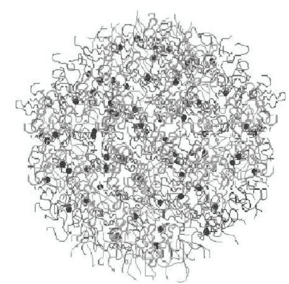


2) _______________

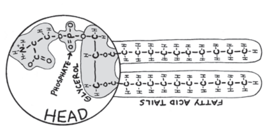


3) ____________

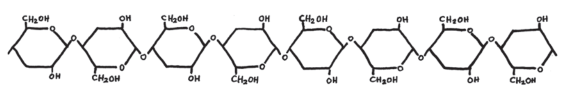
4) _____________



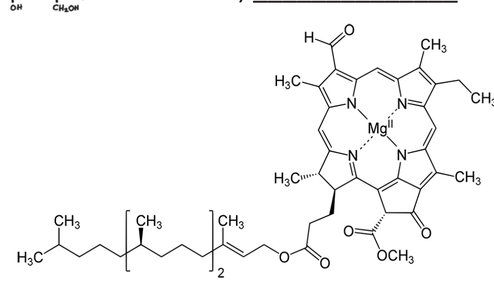
5) _________________



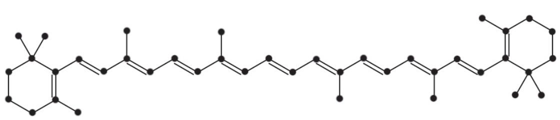
6) _______________



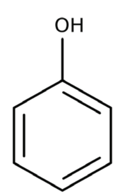
7) ________________



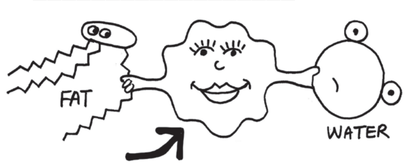
8) _______________



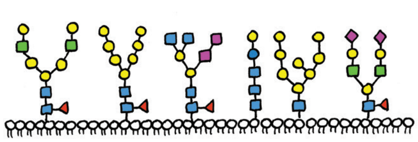
9) ____________



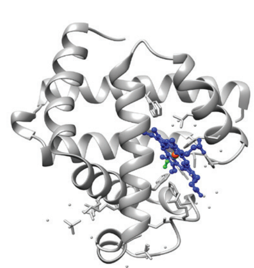
10) ___________________



11) ___________________

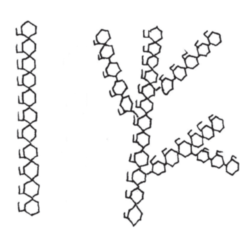


12) _______________



13) _______________

14) _______________



enzyme, phospholipid, glucose, cellulose, carotene, micelle, amino acid, phenol, oligosaccharides, myoglobin, myosin, chlorophyll, sucrose, triglycerides, emulsifier, starch, gluten

ACTIVITY 5.3 Meet the "nightshades" (Solanaceae family of plants) *(so-LAN-uh-SEE-uh)*

In this chapter we learned that potatoes and peppers and tomatoes all belong to the same family of plants, the Solanaceae, often called the "nightshades." All the members of this family make an **alkaloid** chemical. We've met two of these alkaloids: **capsaicin** and **solanine.** Another alkaloid you may have heard of is **nicotine**, the addictive chemical in cigarettes. Nicotine is made by tobacco plants, which are members of the Solanaceae.

Of the four major types of alkaloids, the **tropanes** are the least well-known. One of the most interesting and useful tropanes is **atropine**, a chemical that in high doses is a harmful stimulant, but in low doses becomes an essential medicine. Eye doctors use atropine eye drops to dilate pupils so they can get a better look at the inside of their patients' eyes. The action of atropine on the eye was discovered a long time ago. During the Renaissance period, Italian women would take the juice of the "**bella donna**" plant (also known as the deadly nightshade) and squeeze it into their eyes to open their pupils, thinking that this would make them more attractive. Another medical use for atropine is to reverse the effects of insecticide poisoning or exposure to gases used in chemical warfare.

One of the most unusual flowering plants is a member of this family: the **moonflower**. The flower is large and white, and has 5 petals that unfurl in the evening. The flower stays open all night then closes in the morning. The flowers smell good, but if you crush the leaves or stems they are said to stink like rotten peanut butter. Moonflower plants produce atropine as well as hyoscine, a chemical used to treat motion sickness.

There are thousands of plants in the Solanaceae family, many with strikingly beautiful flowers.


bella donna


jimson weed


petunia


moonflower unfurling


flower of potato


many varieties of tomatoes


tomatillo


many varieties of peppers


eggplant (aubergine)


tobacco

ACTIVITY 5.4 Fifth installment of "Chew It Over," a group game to be played during a meal

Here is another round of questions for you to use at a mealtime that you share with family or friends. These questions relate to the topics we learned about in this chapter. Again, you can use these questions in a varity of ways. You can be the quiz master and determine who gets which questions, or you can cut the questions out of the book and put them into a bag or bowl and let people choose a question randomly. The answers on are the back of this page.

CHAPTER 5: MAIN COURSE 1) Which U.S. state as a potato museum and is known as the potato state? a) Idaho b) Montana c) Oregon d) Washington	CHAPTER 5: MAIN COURSE 2) How many species of fish can you name that are likely to be in your local food store?
CHAPTER 5: MAIN COURSE 3) What are these animals called once they are cooked and served for dinner? (Name a meat for each one.) a) cow b) sheep c) pig d) young calf	CHAPTER 5: MAIN COURSE 4) JOKES Why is it so hard to keep a secret on a farm? What day of the week do potatoes hate?
CHAPTER 5: MAIN COURSE 5) There is a hotness scale for peppers, called the Scoville scale. Green bell peppers score less than 100. Jalepeños can score as high as 10,000. Guess the score of the hottest peppers in the world (such as Carolina Reaper).	CHAPTER 5: MAIN COURSE 6) Guess which country eats more potatoes--United States or Germany?
CHAPTER 5: MAIN COURSE 7) WHICH STATEMENT IS FALSE? 1) Marie Antoinette wore potato flowers in her hair. 2) Napoleon ate potatoes for breakfast every day. 3) Thomas Jefferson introduced French fries to America.	CHAPTER 5: MAIN COURSE 8) WHICH STATEMENT IS FALSE? 1) All peppers start out green, then turn yellow or red. 2) Birds can't sense the hotness of spicy peppers. 3) Peppers were discovered about 1,000 years ago. 4) Bell peppers can be purple.
CHAPTER 5: MAIN COURSE 9) How many varieties of potatoes can you name? How many ways of cooking pototoes can you name?	CHAPTER 5: MAIN COURSE 10) WHICH STATEMENT IS FALSE? 1) Peppers have more vittamin C than oranges. 2) Peppers originally came from India. 3) Sweet peppers and hot chili peppers are members of the same species.
CHAPTER 5: MAIN COURSE 11) Which person at your table can tolerate the hottest spices? Which person has the lowest tolerance for spicy foods?	CHAPTER 5: MAIN COURSE INTERESTING FACT: In November, 2021, a family in New Zealand accidentally discovered a giant potato growing in their garden. It weighed over 17 pounds (8 kg). They named it Doug. Last we heard, Doug was still in their freezer.

1) a) Idaho
2) Answers will vary. In the U.S., common species are tilapia, salmon, mahi mahi, tuna, sole, halibut, cod, perch, flounder.
3) cow: beef, steak / sheep: mutton / pig: pork (bacon, ham) / young calf: veal
4) Because the corn have ears, the potatoes have eyes, and the bean stalk. / Fry-day 5) 1.6 million
6) Germany. The average German eats over 200 pounds per year, the average American eats about 140 pounds. 7) #2
8) #3 Peppers have been discovered in archaeological sites dating back to 2,000-3,000 BC.
9) Popular in USA: Russet, Yukon gold, fingerlings, red, white, Adirondack blue, Kennebec (Your area may have others.)
Mashed, baked, French fries, hashbrowns, potato pancakes, twice-baked, gnocchi, au gratin, tater tots, potato salad, potato chips, stuffed potato skins, potato soup, and others you may have in your area.
10) #2 Peppers are native to South America.